USE OF COAL DRYING TO REDUCE WATER CONSUMED IN PULVERIZED COAL POWER PLANTS

QUARTERLY REPORT FOR THE PERIOD July 1, 2005 to September 30, 2005

by

Edward Levy

Report Issued October 2005

DOE Award Number DE-FC26-03NT41729

Energy Research Center
Lehigh University
117 ATLSS Drive
Bethlehem, PA 18015

DISCLAIMER

"This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

ABSTRACT

This is the eleventh Quarterly Report for this project. The background and technical justification for the project are described, including potential benefits of reducing fuel moisture using power plant waste heat, prior to firing the coal in a pulverized coal boiler.

During this last Quarter, the development of analyses to determine the costs and financial benefits of coal drying was continued. The details of the model and key assumptions being used in the economic evaluation are described in this report.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Background

Low rank fuels such as subbituminous coals and lignites contain significant amounts of moisture compared to higher rank coals. Typically, the moisture content of subbituminous coals ranges from 15 to 30 percent, while that for lignites is between 25 and 40 percent, where both are expressed on a wet coal basis.

High fuel moisture has several adverse impacts on the operation of a pulverized coal generating unit. High fuel moisture results in fuel handling problems, and it affects heat rate, mass rate (tonnage) of emissions, and the consumption of water needed for evaporative cooling.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. In particular, the project involves use of power plant waste heat to partially dry the coal before it is fed to the pulverizers. Done in a proper way, coal drying will reduce cooling tower makeup water requirements and also provide heat rate and emissions benefits.

The technology addressed in this project makes use of the hot circulating cooling water leaving the condenser to heat the air used for drying the coal (Figure 1). The temperature of the circulating water leaving the condenser is usually about 49°C (120°F), and this can be used to produce an air stream at approximately 43°C (110°F). Figure 2 shows a variation of this approach, in which coal drying would be accomplished by both warm air, passing through the dryer, and a flow of hot circulating cooling water, passing through a heat exchanger located in the dryer. Higher temperature drying can be accomplished if hot flue gas from the boiler or extracted steam from the turbine cycle is used to supplement the thermal energy obtained from the circulating cooling water. Various options such as these are being examined in this investigation.

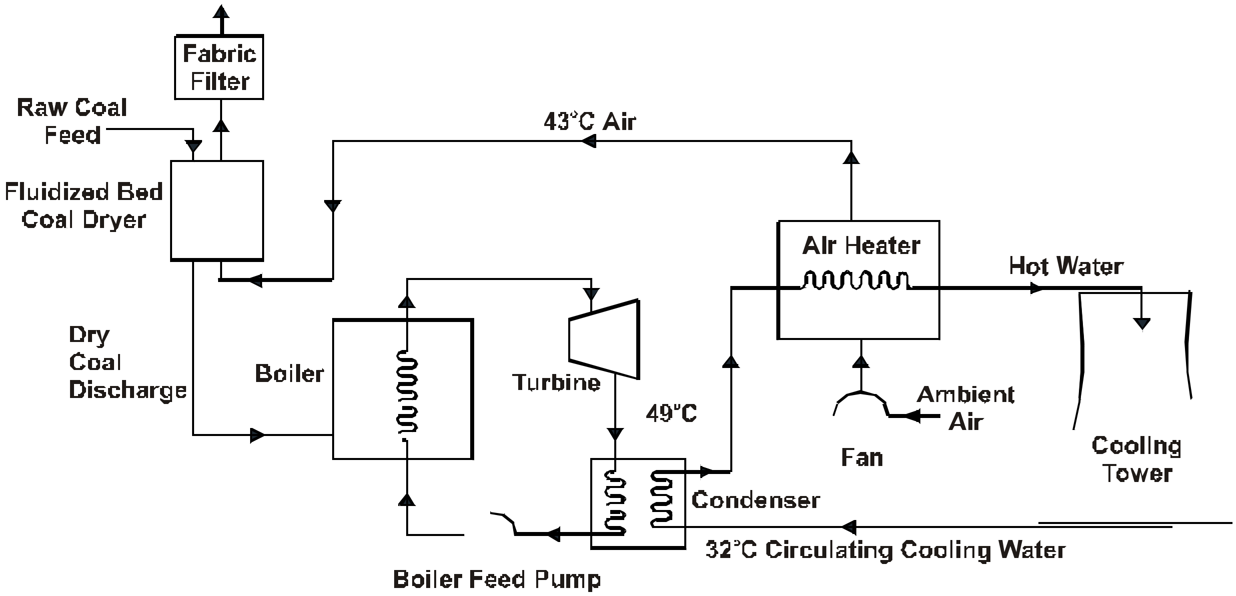

Figure 1: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 1)

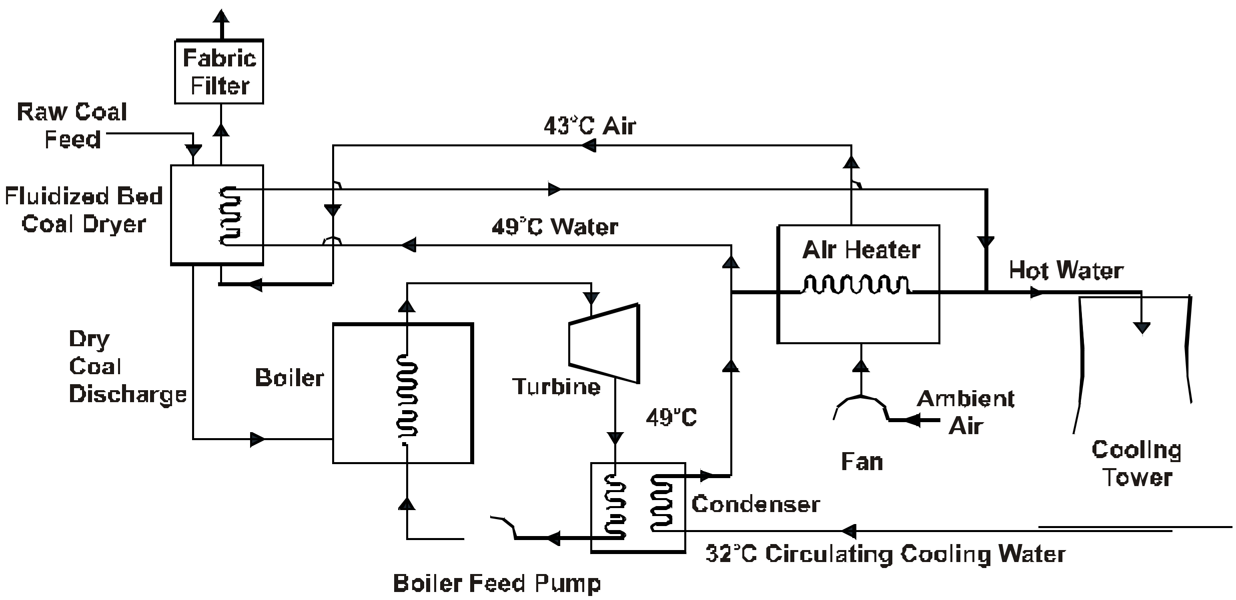

Figure 2: Schematic of Plant Layout, Showing Air Heater and Coal Dryer (Version 2)

Previous Work

Two of the investigators (Levy and Sarunac) have been involved in work with the Great River Energy Corporation on a study of low temperature drying at the Coal Creek Generating Station in Underwood, North Dakota. Coal Creek has two units with total gross generation exceeding 1,100 MW. The units fire a lignite fuel containing approximately 40 percent moisture and 12 percent ash. Both units at Coal Creek are equipped with low NO_x firing systems and have wet scrubbers and evaporative cooling towers.

A coal test burn was conducted at Coal Creek Unit 2 in October 2001 to determine the effect on unit operations. The lignite was dried for this test by an outdoor stockpile coal drying system. On average, the coal moisture was reduced by 6.1 percent, from 37.5 to 31.4 percent. Analysis of boiler efficiency and net unit heat rate showed that with coal drying, the improvement in boiler efficiency was approximately 2.6 percent, and the improvement in net unit heat rate was 2.7 to 2.8 percent. These results are in close agreement with theoretical predictions (Figure 3). The test data also showed the fuel flow rate was reduced by 10.8 percent and the flue gas flow rate was reduced by 4 percent. The combination of lower coal flow rate and better grindability combined to reduce mill power consumption by approximately 17 percent. Fan power was reduced by 3.8 percent due to lower air and flue gas flow rates. The average reduction in total auxiliary power was approximately 3.8 percent (Ref. 1).

This Investigation

Theoretical analyses and coal test burns performed at a lignite fired power plant show that by reducing the fuel moisture, it is indeed possible to improve boiler performance and unit heat rate, reduce emissions and reduce water consumption by the evaporative cooling tower. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

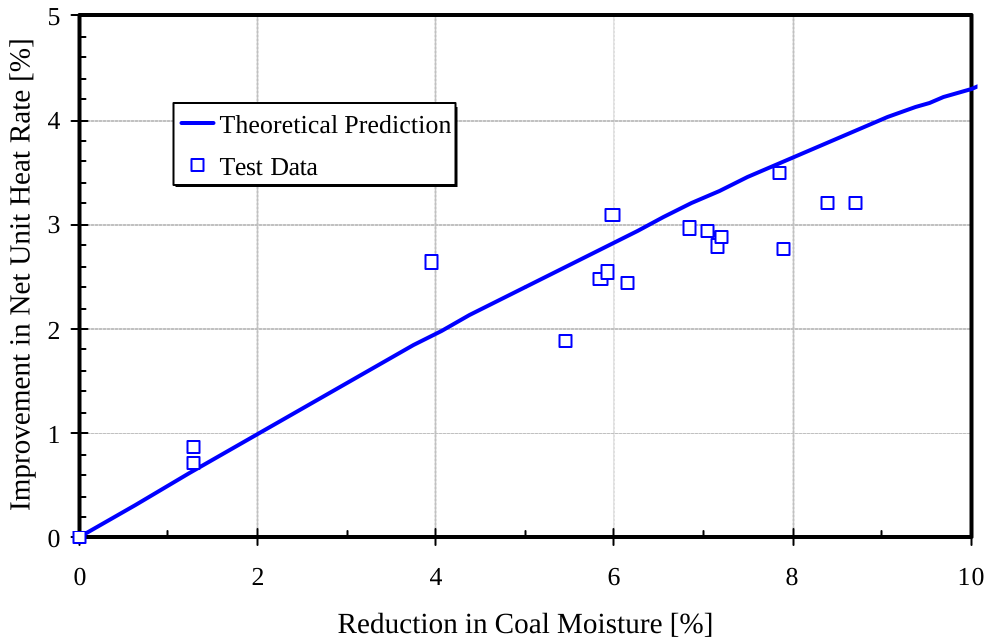

Figure 3: Improvement in Net Unit Heat Rate Versus Reduction in Coal Moisture Content

The present project is evaluating low temperature drying of lignite and Power River Basin (PRB) coal. Drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of the various drying options, along with the development of an optimized system design and recommended operating conditions.

The project is being carried out in five tasks. The original Task Statements included experiments and analyses for both fluidized bed and fixed bed dryers (see previous Quarterly Reports). After the project was started, it became clear there is no advantage to using fixed bed dryers for this application. For this reason, the technical scope was changed in June 2004 to emphasize fluidized bed drying. The Task Statements in this report reflect this change in emphasis.

Task 1: Fabricate and Instrument Equipment

A laboratory scale batch fluidized bed drying system will be designed, fabricated and instrumented in this task. **(Task Complete)**

Task 2: Perform Drying Experiments

The experiments will be carried out while varying superficial air velocity, inlet air temperature and specific humidity, particle size distribution, bed depth, and in-bed heater heat flux. Experiments will be performed with both lignite and PRB coals. **(Task Complete)**

Task 3: Develop Drying Models and Compare to Experimental Data

In this task, the laboratory drying data will be compared to equilibrium and kinetic models to develop models suitable for evaluating tradeoffs between dryer designs. **(Task Complete)**

Task 4: Drying System Design

Using the kinetic data and models from Tasks 2 and 3, dryers will be designed for lignite and PRB coal-fired power plants. Designs will be developed to dry the coal by various amounts. Auxiliary equipment such as fans, water to air heat exchangers, dust collection system and coal crushers will be sized, and installed capital costs and operating costs will be estimated**. (Task Complete)**

Task 5: Analysis of Impacts on Unit Performance and Cost of Energy

Analyses will be performed to estimate the effects of dryer operation on cooling tower makeup water, unit heat rate, auxiliary power, and stack emissions. The cost of energy will be estimated as a function of the reduction in coal moisture content. Cost comparisons will be made between dryer operating conditions (for example, drying temperature and superficial air velocity). **(Task in Progress)**

EXECUTIVE SUMMARY

Background

Low rank fuels such as subbituminous coals and lignites contain relatively large amounts of moisture compared to higher rank coals. High fuel moisture results in fuel handling problems, and it affects station service power, heat rate, and stack gas emissions.

This project deals with lignite and subbituminous coal-fired pulverized coal power plants, which are cooled by evaporative cooling towers. The project involves use of the hot circulating cooling water leaving the condenser to provide heat needed to partially dry the coal before it is fed to the pulverizers.

Recently completed theoretical analyses and coal test burns performed at a lignite-fired power plant showed that by reducing the fuel moisture, it is possible to reduce water consumption by evaporative cooling towers, improve boiler performance and unit heat rate, and reduce emissions. The economic viability of the approach and the actual impact of the drying system on water consumption, unit heat rate and stack emissions will depend critically on the design and operating conditions of the drying system.

This project is evaluating alternatives for the low temperature drying of lignite and Power River Basin (PRB) coal. Laboratory drying studies are being performed to gather data and develop models on drying kinetics. In addition, analyses are being carried out to determine the relative costs and performance impacts (in terms of heat rate, cooling tower water consumption and emissions) of drying, along with the development of an optimized system design and recommended operating conditions.

Results

Analyses to determine the costs and financial benefits of coal drying are well underway. Capital and operating costs have been estimated and estimates are being developed of the financial benefits of coal drying. These include reduced fuel costs and ash disposal costs, avoided costs of emissions control, changes in station service power, reduced water use, reduced mill maintenance costs and reduced lost generation due to mill outages. The methodology and key assumptions being used to estimate the costs and benefits are described.

METHODOLOGY AND KEY ASSUMPTIONS BEING USED IN THE ECONOMIC EVALUATION OF COAL DRYING

Previous reports from this project contain descriptions of analyses carried out to compute the effects of coal drying on unit heat rate, station service power, stack emissions, and water consumption for evaporative cooling. The remaining work to be done in the project consists of the analyses in Task 5 to determine the cost effectiveness of coal drying and the effects of drying system design and process conditions on drying costs. This report describes the methodology and key assumptions being used to estimate the costs and benefits of coal drying and lays the groundwork for comparing the cost effectiveness of the various coal drying processes examined in this project. The cost analyses being carried out in this study are for a 537 MW lignite power plant.

Capital and Operating Costs

The previous analyses used mass and energy balances to determine the effects of coal product moisture on unit performance and emissions. Those analyses also generated information on flow rates of coal and flow rates and temperatures of air, flue gas and cooling water at various state points in the system. This information was then used to determine the required sizes and operating conditions of key components of the drying system such as fluidized bed dryers, fans, heat exchangers and baghouses. Estimates of installed capital costs were obtained from vendors and from the open literature. Where possible, cost estimates were obtained from independent sources as a cross check on the numbers being used. The annual fixed charge, which includes interest, depreciation, taxes and insurance, was calculated assuming a 20 year life and a 7.5% interest rate.

It was assumed the drying system operates 24 hours a day and seven days a week. Costs for operating and maintenance manpower were estimated by assuming one operator for all the dryers during each operating shift and two maintenance personnel for all the dryers during one shift each day. The operating costs include salaries and wages, employee benefits, supervision, and supplies for operation and maintenance. The operating costs also include electrical power to drive the fluidization air fans, and this is included as a component in the total station service power, as described below.

Benefits

The potential financial benefits fall into six categories:

- Reduced Fuel Costs
- Reduced Ash Disposal Costs
- Avoided Costs of Emissions Control
- Reduced Station Service Power (or, in some cases, the cost of increased station service power)
- Water Savings
- Reduced Mill Maintenance Costs
- Reduced Lost Generation Due to Mill Outages

The factors being considered in quantification of these benefits are described below:

Reduced Fuel Costs

The results presented in previous reports show that use of power plant waste heat to dry the coal before pulverizing it results in a reduction in unit heat rate. Thus, for a fixed gross power output, the percentage improvement in heat rate results in a proportional percentage reduction in coal use.

Reduced Ash Disposal Costs

A reduction in coal use results in a reduction in ash disposal costs.

Avoided Costs of Emissions Control

The reduction in coal use also leads to reductions in emissions of SO_2, NO_x, CO_2 and Hg. Assuming a fixed moisture-free composition of coal fed to the plant, the rates of emissions of SO_2 and CO_2 are directly proportional to the rate at which coal is burned, and thus the percentage reductions in emissions of SO_2 and CO_2 are equal to the percentage reductions in heat rate. Just with the SO_2 and CO_2, the rate of emissions of Hg will be reduced due to a reduction in the rate at which moisture-free coal is burned. But in addition, there is evidence from laboratory experiments and theoretical analyses that a reduction in flue gas moisture results in enhanced Hg oxidation and thus enhanced Hg capture by particulates. If this happens, the percentage reduction in Hg emissions will be larger than the percentage reduction in heat rate. The magnitude of this effect will be site specific and field tests would be needed to quantify the magnitude of the reductions in Hg emissions. Similarly, the impact of coal drying on NO_x emissions is site specific. For purposes of the analyses carried out in this investigation, percentage reductions of the emissions of NO_x, H_g, SO_2 and CO_2 are all assumed to equal the percentage change in heat rate.

The costs of emissions being used to estimate the avoided costs for each of the four gaseous pollutants are shown below.

NO_x	\$2,500/ton
SO_2	\$750/ton
Hg	\$30,000 to \$60,000/lbm
CO_2	\$15 to \$30/ton

Reduced (or Increased) Station Service Power

The components of station service power affected by coal drying include the induced draft and forced draft fan power, mill power and power for the fluidization air fans. Coal drying results in a decreased flow rate of combustion air and a decreased flow rate of flue gas, thus reducing the power requirements for the forced draft and induced draft fans. Fan power is assumed to be proportional to the air or flue gas flow rate.

Pulverizer power requirements depend on the flow rate of coal through the pulverizers and the energy requirement for grinding per ton of coal. Coal drying results in an increase in the Hardgrove grindability index of the coal, thus causing a reduction in the energy requirements for grinding per ton of coal. Both the reduced coal flow rate and the reduction in grinding energy per ton of coal are being taken into account in this analysis.

As noted above, coal drying results in a reduction of the power requirements for the coal pulverizers and for the induced draft and forced draft fans. It also leads to the addition of a new power component…..the power required to drive the fans for the fluidization air. The flow rate of fluidization air depends on dryer size, which, in turn, depends on the temperature(s) of the heat source(s) used for drying and the difference between the inlet and exit coal moisture levels. To determine the effects of dryer size on the economics, separate analyses are being carried out for drying systems operating at different drying temperatures and with different coal product moisture levels.

Water Savings

Reductions in makeup water requirements for evaporative cooling towers due to coal drying will result in avoided costs for water. The cooling tower analyses indicate water reductions approaching 500,000 gallons per day are possible for a 537 MW lignite fired power plant. Information is being gathered on the cost of water for large industrial users in various parts of the United States.

In some circumstances, there will be additional financial benefits if the reduction in makeup water requirements results in a decreased need to derate the unit due to a scarcity of water for cooling. Sensitivity calculations will be carried out to determine the impact of the potential avoidance of derating on the economics.

Reduced Mill Maintenance Costs

Pulverizer maintenance requirements depend on coal feed rate and on the grinding characteristics of the coal. Both parameters affect wear of the grinding surfaces inside the mill and, consequently, the required frequency for mill maintenance. Erosion of mill internals is also dependent on coal feed rate and on the flow rate of primary air needed to dry the coal once it reaches the mill. Predrying the coal in a fluidized bed before it reaches the mill results in lower primary air flow rates through the mill and reduced maintenance costs. Information is being gathered from pulverizer vendors and from utility companies in an effort to quantify the impacts of coal drying on mill maintenance costs.

Reduced Lost Generation Due to Mill Outages

Many power plants firing high moisture, low rank coals were originally designed to operate with low moisture Eastern coals. When the conversion to subbitminous coals occurred, they were forced to operate without any excess mill capacity. Power plants such as these, if retrofitted with a coal drying system, would then have excess mill capacity, which would make it possible in the event of a mill outage (either scheduled or unscheduled) to continue to generate electricity without a reduction in power output. It is planned to include scenarios involving reductions in lost generation in the economic analysis.

CONCLUSIONS

Analyses to determine the costs and financial benefits of coal drying are well underway. The model and key assumptions being used in the economic evaluation are described in this report, and it is expected that results from the analyses will be available for reporting in the next quarterly report.

PLANS FOR THE NEXT QUARTER

It is planned to complete the Task 5 analyses on the economics of coal drying in the next quarter.

REFERENCE

1. Bullinger, C., M. Ness, N. Sarunac, E. K. Levy, “Coal Drying Improves Performance and Reduces Emissions,” Presented at the 27th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, March 4-7, 2002.